A new approach for Vehicle Accident Prevention on the highway using Mobile WiMAX

Sang-Eon Kim, Han-Lim Kim, Jong-Sam Jin, Seong-Choon Lee

Wireless Technology Department, Central R&D laboratory, KT
17 Woomyeon-Dong, Seocho-Gu, Seoul, 137-792, Korea

{sekim, nangel, jongsam, lsc}@ kt.com

ABSTRACT

Recently, it is focused on the vehicular ad hoc network (VANET) which is one of the applications of mobile ad hoc networks for vehicle safety and accident prevention in this research area. The major challenges for VANET are media access control (MAC) for inter-vehicle direct communication, dynamic network topology due to mobility of the vehicle, security for communication and so on.

This paper proposes new approach to resolve above problems based on mobile WiMAX technologies. The proposals include network architecture for inter-vehicle communication, requirements of the network elements for 160 Km per hour speed. A multicast technology is required for VANET application such as emergency information to prevent a series of accident. However, multicast application is not possible in the current mobile WiMAX both point-to-multipoint mode and mesh mod due to on-going standard process at WiMAX Forum.

We verify the network architecture, requirements and technical feasibility based on testbed which can test 160Km vehicular speed. The results of the research project show that mobile WiMAX is competitive to the wireless access for vehicular environments (WAVE) for communication technology the purpose of intelligent transport systems.

Keywords: VANET, V2I, WiMAX, WiBro

1 INTRODUCTION

Most of the traffic accidents are known to occur when the drivers don't know urgent running condition around him. The driver in the vehicles controls the brake or lane change without right information related to road condition, speed of the nearby vehicle, traffic signals and so on. Wireless communication technology can be considered to provide driving information for safety. A vehicular ad hoc network (VANET) is a communication technology for both vehicle to vehicle (V2V) which is one of the mobile ad-hoc network (MANET) applications [1] and vehicular to infrastructure (V2I) [2].

The purposes of the VANET research are providing safety for vehicle and driver. The VANET also contributes to preventing chain collision from unexpected vehicular conditions or falling by delivering the information on driving information and road conditions. It can support improved traffic control by monitoring road condition and traffic information. Therefore, it is important to provide vehicle information, road condition, traffic information for the application. An example of VANET application are described four categories with 18 kinds of applications for active safety, 7 kinds of applications for public service, 11 kinds of applications for improved driving and 14 kinds of applications for business/entertainment [3]. The vehicle safety communication (VSC)[1] project reports a list of identified application which is divided into two categories with 34 safety applications and 11 non-safety applications [4]. The Communication for eSafety projects[2] proposes 19 kinds of applications for traffic safety, 7 kinds of applications for traffic efficiency and 14 kinds of value added services [24].

There are many technical challenges for V2V communication which is mostly based on MANET [5-6]. The research interests for MANET are media access control [7-8], topology control [9-10], network issues [11-13], service discovery [14], quality of service [15] and so on. Also, mesh networks [16] can be considered for V2V communication. A wireless communication technology for V2I can be used commercial infrastructure such as 2G, 3G, mobile WiMAX [17-18]. Also, network mobility [19], Mobile IP [20-22] technologies can be required to support mobility for V2I.

---

[1] http://www.nhtsa.dot.gov/
[2] http://www.comesafety.org/

There are many research projects [23-25] including Cooperative Vehicle-infrastructure Systems (CVIS)[3], Geographic addressing and routing for vehicular communications (GeoNet)[4], PReVENTive and Active Safety Applications (PReVENT)[5], SEcure VEhicle Communication (SEVECOM)[6], Smart Vehicles on Smart Roads (SAFESPOT)[7], eSafetySupport[8], Network On Wheels (NOW)[9], CO-OPerative SystEms for Intelligent Road Safety (Coopers)[10] and Global System for Telematics (GST)[11] to realize a VANET.

Most of the application for VANET based on V2I rather than V2V [4]. There are many research project based on dedicated short range communication (DSRC) at 5.9GHz for V2I but it is not cost effective compared with WiMAX and wireless broadband (WiBro). The WiMAX is focused on 5 and 10MHz bandwidths in several band classes in 2.3GHz, 2.5GHz and 3.5GHz. The WiBro, one of the WiMAX system profile, operates with 8.75MHz bandwidth in 2.3GHz band class. The WiBro provides high speed Internet with mobility functions and more wide radio coverage per base station (BS) than DSRC. This means WiBro terminals can provide additionally V2I application based on Internet access in the car. Therefore, WiBro can provide V2I application with cost effective. This paper proposes to provide V2I solutions by WiBro technology which is one of the technical profiles for mobile WiMAX. The VANET related projects are not tried to use WiBro or mobile WiMAX yet.

We discuss communication requirements and propose network architecture with WiBro for wireless communication technology to support VANET next section. Section 3 proposes algorithms to implement based on WiBro, and section 4 shows a part of experimental results of collision avoidance, which is one of the VANET applications, among cars in the same direction from accident. We conclude with further research issues to implement and verify over WiBro.

2 VANET USING MOBILE WIMAX

2.1 Communication Requirements for VANET

Wireless network for VANET should support point-to-multipoint and point-to-point transmission mode based on services. The information can be transmitted either event-driven or periodical. If the information is periodically generated, interval time should be defined. The wireless communication technology should be satisfied with the maximum duration of time to transmit as well as the maximum distance between source and destination. The maximum required range of communication is explained to 1Km for approaching emergency vehicle warning [4]. The minimum update rate is every second for approaching emergency vehicle warning and the allowable latency is less than one second.

The ITS communication architecture for VANET is described and compared access technologies in [24]. According to the [24], we can decide that the WiMAX is the most appropriate access technology for VANET. They review access technologies which divided into three categories: short range/ad-hoc, cellular and digital broadcast. The technologies for short and ad-hoc are including CEN DSRC at 5.8GHz based on CEN EN 12253-2004, European 5.9GHz ITS based on IEEE 802.11p, wireless local area network specified at 5GHz by IEEE 802.11p, infrared based on ISO21214. The cellular technologies are encompassed WiFi, also known as wireless fidelity, at 2.4GHz based on IEEE 802.11a/g, WiMAX at 2.3GHz, 2.5GHz and 3.5GHz based on IEEE 802.16 and IEEE 802.16e, GSM/GPRS at 800MHz and 1.8GHz based on GSM standard, UMTS at 800MHz and 2GHz based on 3GPP standard. Almost all of the applications are based on V2I, therefore cellular technologies can be considered more important than ad-hoc technologies. Moreover, cellular technologies are technically verified whereas ad-hoc technologies are still required research and development.

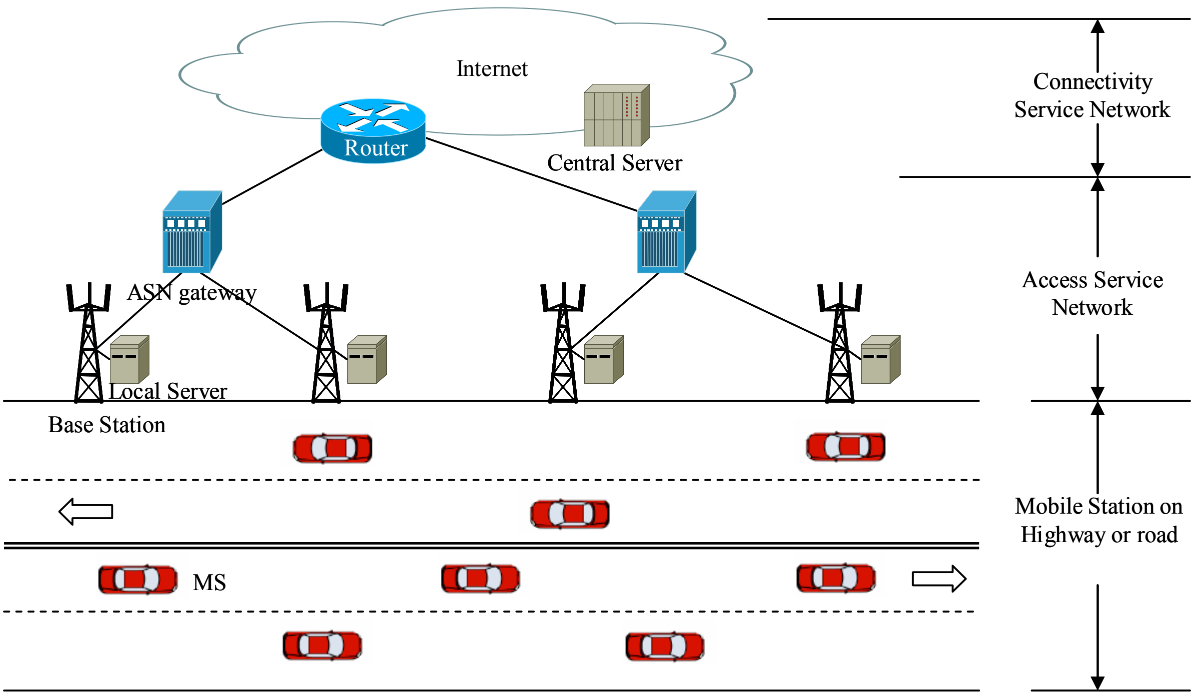
2.2 V2I Architecture with Mobile WiMAX

[3] http://www.cvisproject.org/
[4] http://www.geonet-project.eu/
[5] http://www.prevent-ip.org/
[6] http://www.sevecom.org/
[7] http://www.safespot-eu.org/
[8] http://www.esafetysupport.org/
[9] http://www.network-on-wheels.de/
[10] http://www.coopers-ip.eu/
[11] http://www.gstforum.org/

Figure 1 illustrates network architecture for VANET architecture based on WiMAX which consists of several logical network entities including subscriber station (SS) or mobile station (MS), access service network (ASN) and connectivity service network (CSN) [26-27]. The SS/MS is user equipment set providing wireless connectivity. The SS is for fixed device terminal and it is not required to support handover capability. The MS providing handover function is installed or embedded in car for VANET and it should support handover.

ANS is a set of network functions to provide wireless connection based on [17-18] and WiMAX system profile. These functions are including media access control for MS, transfer of authentication, authorization and accounting (AAA) messages by RADIUS [28] or diameter [29], preferred network discovery and selection, radio resource management and Internet protocol (IP) connectivity. ASN is composed of BS and ASN gateway which connects several BSs based on cell planning. Local server is required for VANET application. The local server processes collected information from the MSs in vehicles and sends warning messages to MSs. The messages types depend on the application such as warning for dangerous road features, danger of collisions, accident information and so on.

CSN is a set of network functions that provide IP connectivity service to MS. The CSN comprise network elements such as router, gateway for interworking and various kinds of servers. These servers are including DHCP [30] for IP address allocation, AAA proxy/server, user database, home agent for mobility management, central server for VANET application and so on.



(Figure 1) VANET architecture with mobile WiMAX

There are two additional network elements to provide V2I application with WiMAX architecture: local server and central server. The MS requires WiBro interface and additional features for VANET application which is ignition key status, temperature of water, voltage of battery and so on.

2.3 Requirements for Network Elements to prevent Collision

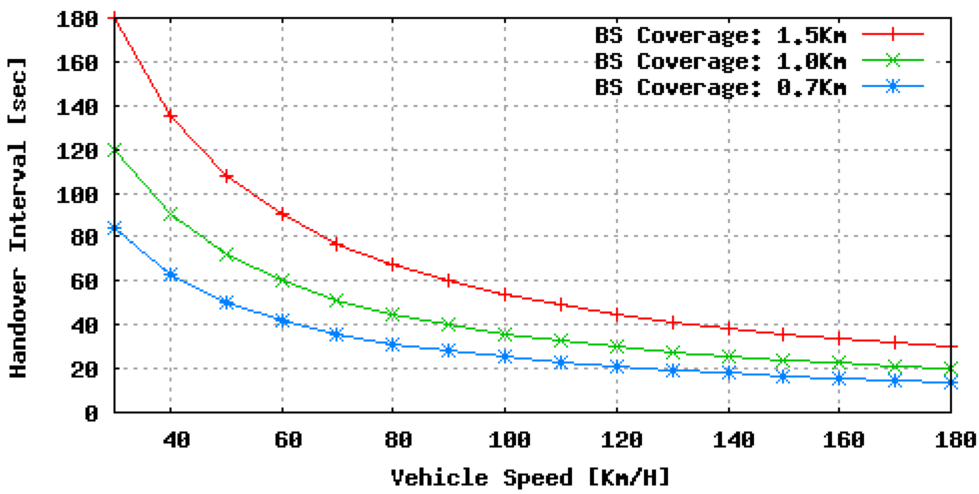
We are focused on forward and rear collection warning on the highway based on mobile WiMAX architecture. Therefore, the requirements are described in the viewpoint of mobile WiMAX.

2.3.1 Requirements for MS

The IEEE 802.16e standard [18] defines two operational modes to conserve MS power during the inactive state to minimize usage of the serving BS air-interface resources: sleep mode and idle mode. Sleep mode is a

state that the MS is considered unavailable to serving BS. But the serving BS observes downlink and uplink traffic of the MS. Implementation of sleep mode is optional for the MS and mandatory for the BS. When the MS enters the sleep mode, the BS does not transmit data to the MS. The MSs can initiate sleep mode with sleep request (MOB_SLP_REQ) message and the BS replies sleep response (MOB_SLP_RSP) message. In idle mode, the MSs are periodically available to receive downlink broadcast traffic messaging without registration at a specific BS as the MS traverses among multiple BSs. The MS can initiates idle mode sending de-registration request (DREG-REQ) message to the BS and receiving de-register command (DREG-CMD) message from BS.

However, the MS for VANET application has no requirement neither sleep mode nor idle mode for the following reasons. First, the MS has sufficient power from the vehicle. Second, the MSs are moving on the road or highway, handover is essential and supports periodically as shown in figure 2. For example, the MS performs handover every 36 seconds in 100Km per hour speed, when each BS supports 1Km of cell coverage. If the event such as intersection collision warning and forward/rear collision warning occurred, the MSs can not transmit and receive the warning information within few hundred milliseconds either idle mode or sleep mode. Therefore, the MS is required always awake state to support communication in vehicles.



(Figure 2) Handover intervals

2.3.2 Requirements for Local Server

The local server at the roadside provides two function: information processing and relay. The information processing function is data collection, update and deletion in the cell coverage. The MS in vehicle periodically sends location information such as latitude, longitude and time to the local server. The local server saves location information and maintains for each vehicle. The local server sends related parameters to the newly joined MS in vehicle.

Information relay of local server is distribution function of collected information from MSs. When a vehicle accident occurred, the MS sends accident information to the local server. The local server compares the information between lists of a registered MSs in vehicles and accident information. For example, to prevent forward collision, the local server decides to receiver list that is same direction and influence area based on the results of the compare and sends the warning message to the receiver list. Also, the local server sends accident information to the central server.

The local server requires multicast function to send warning message for a rear vehicle. The multicast transmission reduces the radio resource. However, the commercial WiBro service only supports unicast transmission. Therefore, the local server should provide packet transmission to multiple destinations with unicast. For this, the local server maintains IP address of MS to send in real time based on the location of vehicle in the highway.

2.3.3 Requirements for Central Server

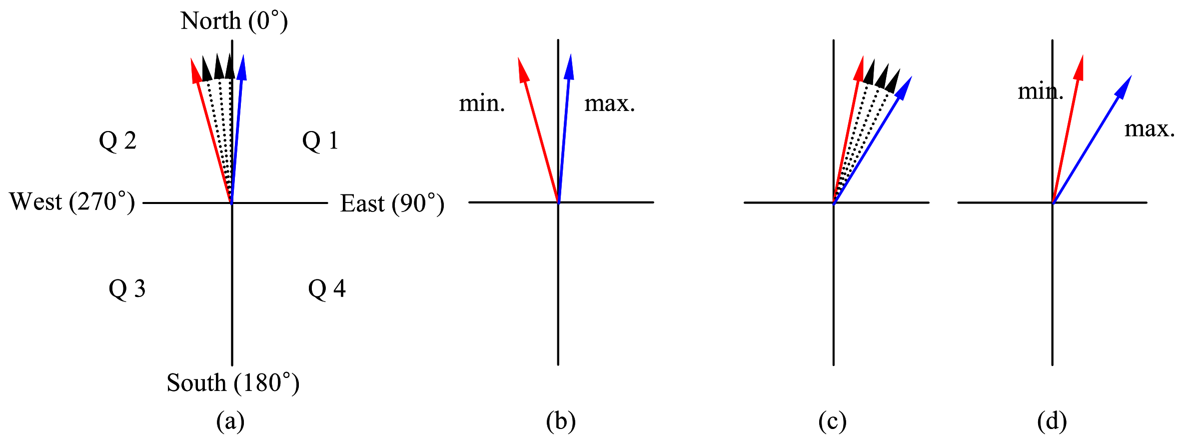
The central server processes integrated information from local servers and produces statistics. The central server requires reporting function which is summarized statistics and displays road status on geographical map at

the screen. The central server can display either accident information or all MS information in vehicles. It depends on application. When the central server displays all MSs on the map, it requires real-time processing capabilities due to movement of the vehicles.

3 ALGORITHMS

3.1 Decision for directional angle of vehicle

The local server maintains location information of recently collected from the number of N MSs in vehicles that is registered. In this paper, movement list indicates location information for the number of N vehicles. When the MS sends location information, the local server updates its location information and directional angle based on examination of change of directional angle. The directional angle is measured at every second and collected five values to decide driving direction. The directional angle consists of minimum, maximum value. The value of a directional angle is 0 degree at north. It is calculated from 0 degree to 360 degree moving clockwise direction. The mean of a directional angle is a division of 360 degree like a directional angle. The minimum value is a smallest directional angle and maximum value is a largest directional angle. But the directional angles are distributed in first quadrant and second quadrant, the minimum value is smallest value in second quadrant and the maximum value is largest value in first quadrant. For example, the MS moves to the north direction when the directional angle changes from the second quadrant to the first quadrant as shown in figure 3. Figure 3 (a) shows 5 direction angles for location information and (b) illustrates minimum directional angle and maximum directional angles from collected information in (a). The intervals to collect information on directional angle depend on extraction from global positioning system (GPS). Figure 3 (c) is another directional angles after change the driving direction due to lane change or curve on the road in the same vehicle as (a).



(Figure 3) Minimum, maximum value for directional angle

3.2 Node selection to receive warning messages

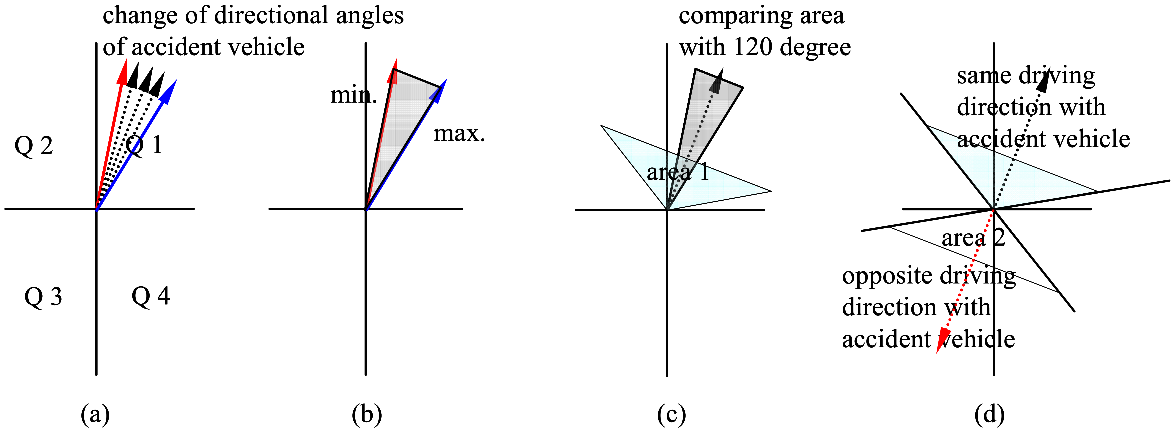
When the local server receives accident information from the vehicle accident, it has to select receiving nodes to send warning messages. The node selection is performed based on driving direction of vehicles and influence area.

3.2.1 Decision for driving direction

The local server compares directional angles of accident vehicle with lists of normally driving vehicles to identify same direction or not. For this, the local servers identify directional angle with maximum and minimum directional angle of accident vehicle. Also, it collects directional angle, maximum value and minimum value from the list of vehicle without accident.

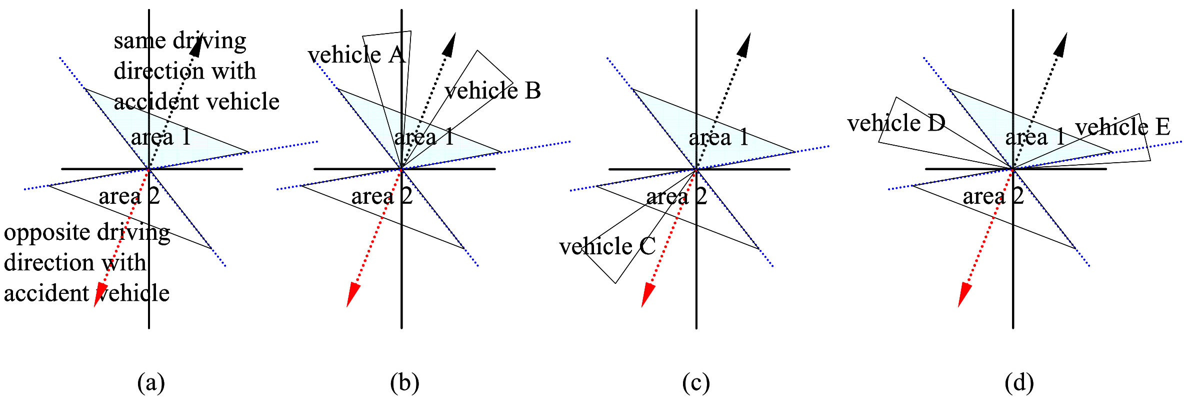
If the difference of directional angle is less than 120 degrees of accident vehicle, the directional angle expands to 120 degrees between maximum and minimum angle to identify driving direction as shown in figure 4 (c). The area 1 in figure 4 (c) is driving direction of accident vehicle. We use the original angles to compare in case of exceeding 120 degrees. We assume that almost all of directional angles are less than 120 degrees of the change except for sharp curve or turning. The area 2 in figure 4 (d) is opposite driving direction of accident vehicle.

We identify the driving direction with directional angle at moment of accident in the local server as shown in figure 5. The local server decides that vehicle A and vehicle B in figure 5 (b) are driving same direction as accident vehicle. The vehicles in area 2 in figure 5 (a) exclude to send warning message. Because the vehicles in area 2 are driving opposite direction compared to accident vehicle. Therefore the local server excludes whether the vehicles change directional angle or not in area 2 because of opposite driving direction as shown in figure 5 (c).



(Figure 4) Creation of comparing area by directional angle of accident vehicle

The local server defers decision to send warning message neither area 1 nor area 2. The local server requires for decision driving direction with more information on directional angle in this area. It may accident vehicle in this area. When two vehicles collide, one sends accident information to the local server. If the other doesn't send accident information, the local server has directional angle like vehicle D or vehicle E as shown in figure 5 (d). The vehicles out of area 1 and area 2 may on the curve far from accident point. In this case, local server decides by classification of influence area such as emergency, warning and careful area.



(Figure 5) Decision of driving direction based on directional angle change

3.2.2 Distance calculation between vehicles

The MS collects location information which is latitude φ and longitude λ by GPS. When the MS moves on the road, we calculate the distance either the distance between the different time for one MS or the distance between the two MS at the same time by haversine formula [31]. We define that Δφ is difference of latitude and Δλ is difference of longitude either the two MSs at the same time or different time for the one MS.

$$\Delta\lambda = \lambda_1 - \lambda_2 \tag{1}$$

$$\Delta\varphi = \varphi_1 - \varphi_2 \tag{2}$$

We calculate the distances between the two points on earth as following [31].

$$d = \mathrm{R} \times \mathrm{C} \tag{3}$$

Where, R is radius of earth. The mean radius is 6,371Km. The C can be expressed as:

$$\mathrm{C} = 2 \times \tan^{-1}\left(\frac{\sqrt{\alpha}}{\sqrt{1-\alpha}}\right) \tag{4}$$

where α can be expressed as:

$$\alpha = \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right) \tag{5}$$

3.2.3 Classification of influence area

We propose influence area to provide information in accordance with driving direction and distance between accident vehicle and driving vehicle on the road or highway. For this purpose, we propose three kinds of influence area: emergency, warning and careful area. The local server sends different messages to the influence area.

The vehicle in emergency area is required immediate action to prevent collision from accident vehicle. Therefore the emergency area can be defined as required areas to operate the break by receiving accident information in the same driving direction. The emergency area depends on the vehicle speed and road type and status. When the vehicle receives emergency message form the local server, the MS in the vehicle displays visible emergency signal and distance to the accident point with audible signal.

The warning area is required to reduce the vehicle speed and to recognize accident. The rear vehicle speed is between half speed and normal speed in the warning area. The driver receives warning messages from the local server for safety. The MS may sufficient displaying visible warning signal and audible signal is optional. The driver can reduce driving speed and any other actions can't take due to driving condition. In this case, the warning area can escape by detour, interchange on highway or clearing accident.

The careful area is required to recognize accident. The driver receives reduced-warning messages for safety with summarized information from the local server. The reduced-warning message consists of visible information without any other information. The driver can search detour or interchange on highway based on receiving reduced-warning message.

3.3 Delay measurement

3.3.1 Time synchronization and calculation

We propose to measure delay time between sending time at the moment of accident and receiving time in the influence area. The purpose of delay measurement is for performance evaluation of WiMAX application for VANET. We use validated GPS signal for a reference time of MSs in vehicles and assume same time for all GPS signal which updates at every second. The more accurate time can be calculated as shown in figure 6.

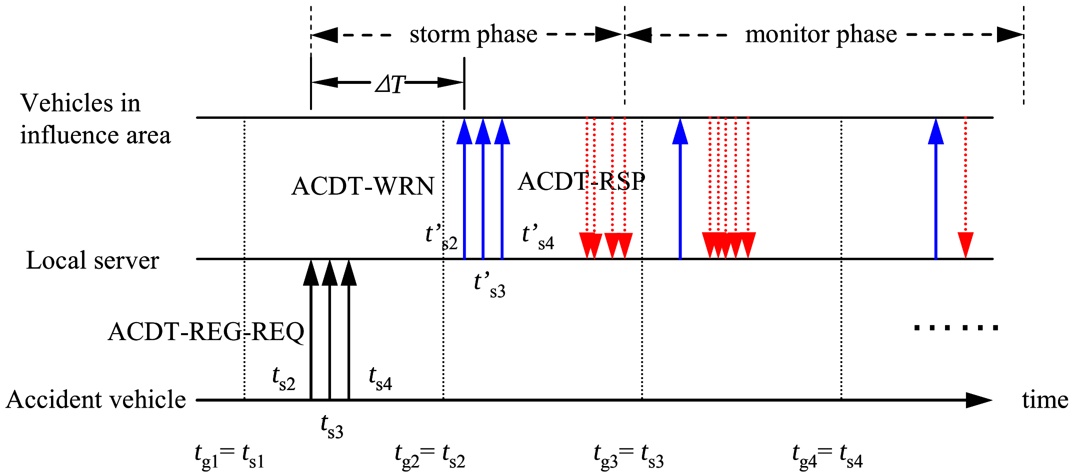
All MSs and local servers receive a clock from GPS signal at every second and write to memory both GPS time (t_{g1}, t_{g2}, t_{g3},…) and system time (t_{s1}, t_{s2}, t_{s3},…). The most recent information is maintained from the memory in MSs and local server and deleted previous time information. For example, when the MS generates an event at t_{s2}, the MS calculate a time as following.

$$\text{event\_time} = t_{s1} + \Delta t = t_{g1} + (t_{s2} - t_{s1}) \tag{6}$$

Where, Δt is a difference between event time and GPS time which is one of the t_{s2} - t_{s1}, t_{s3} - t_{s1}, t_{s4} - t_{s1}, t'_{s2} - t'_{s2} and so on. The granularity of the Δt is microseconds. Therefore, the event time can be calculated at microsecond unit.

3.3.2 Delay measurement

We define ΔT as a propagation delay time from sending time at accident vehicle to receiving time at MS in influence area. We measure ΔT as following.



(Figure 6) Time synchronization with GPS signal and message flow

The accident vehicle sends accident register request messages (ACDT-REG-REQ) to the local server including time information. The ACDT-REG-REQ message is including vehicle identification information, time (t_{arr}), latitude and longitude information for location, directional angle and so on. The ACDT-REG-REQ message uses user datagram protocol (UDP) [32] to reduce session establishment between the MS and the local server. We design that the MS sends three consecutive packets to prevent from loss due to changing radio signal. The three UDP packets are identified by sequence number and the other payload information is same.

The local server broadcast accident warning messages (ACDT-WRN) to MSs in vehicles based on node selection algorithm by UDP packet as soon as receiving the ACDT-REG-REQ. The ACDT-WRN message including time information (t_{aw}), accident identification is also sent three consecutive packets as the same reason for ACDT-REG-REQ.

When the MSs are received ACDT-WRN messages in the emergency area, the MS reply to the local server by accident response (ACDT-RSP) messages including time information (t_{ar}). The ACDT-RSP message is sent one time to reduce radio resource. Because the local server receives lots of ACDT-RSP messages from MSs in the emergency area. This is initial storm phase. The delay time from accident detection to receiving warning message at MSs in emergency area can be expressed as:

$$\Delta T = t_{ar} - t_{arr} \qquad (7)$$

Where t_{arr} denotes time information at the moment of generating ACDT-REG-REQ message, t_{aw} denotes for time of ACDT-WRN and t_{ar} denotes for time of ACDT-RSP. The time information for t_{arr}, t_{aw} and t_{ar} can be calculated by equation (6).

After the storm phase, the local server periodically sends ACDT-WRN messages with one UDP packet which is composed of accident identification with the same as previous packet and new time information (t_{aw}) until closing the accident. This period calls accident monitor phase until closing the accident.

4 EXPERIMENTAL EVALUATION

4.1 Prototype implementation

We have implemented algorithm that described in previous section to the MS and local server. We develop on the Window XP and JAVA environment both MS and local server. The communication interface for the MS is used WiBro and the local server has gigabit Ethernet interface. The WiBro system parameters are shown in <Table 1>. The GPS is mandatory for the MS and optional for the local server. The delay measurement is

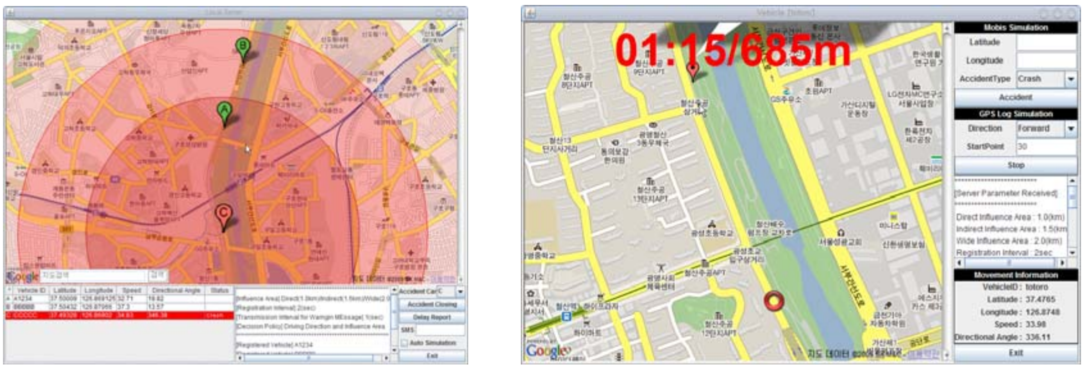
calculated from t_{ar}, t_{arr} which is generated at the MS. All MSs are synchronized timing with GPS receiver described in section 3.

<Table 1> WiBro System Parameters

Frequency domain		Time domain	
sampling frequency	10MHz	ratio of cyclic prefix	1/8
signal bandwidth	8.75MHz	basic OFDMA symbol time	102.4us
subcarrier spacing	9.77KHz	CP time	12.8us
the number of used sub-carriers (including DC sub-carrier)	865: diversity/AMC 841: DL & UL PUSC	OFDMA symbol time	115.2us
The number of data sub-carriers	768: diversity/AMC 720: DL PUSC 560: UL PUSC	TDD frame length	5ms
The number of pilot sub-carriers	96: diversity/AMC 120: DL PUSC 280: UL PUSC	the number of symbol per frame	42
the number of data sub-carriers per sub-channel	48	transmit/receive transition gap	87.2us
		Receive/transmit transition gap	74.2us

4.2 The results of the field Tests

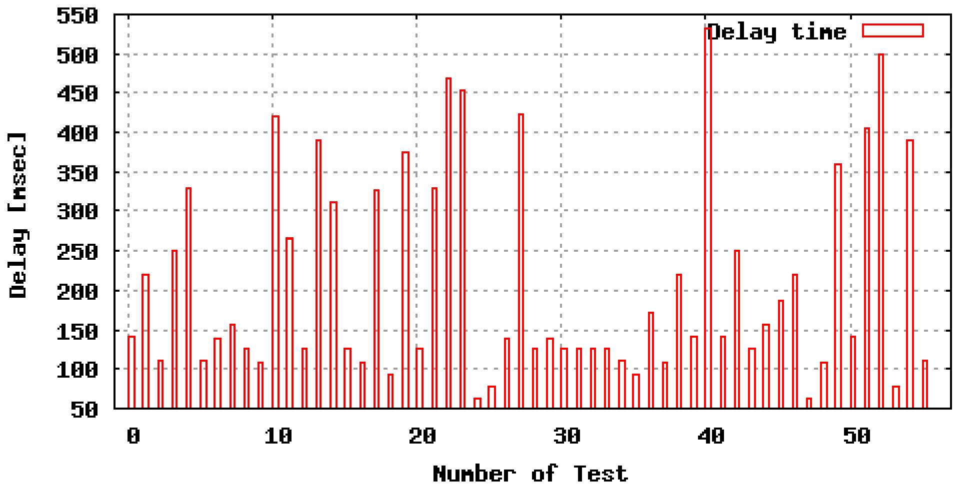
We have verified the proposed algorithm by field trials. We tested on the real world with prototype: local server and MS. The prototype for local server includes function for central server. The local server and MS in the vehicle connect Internet by Ethernet and WiBro, respectively. We choose the two area for the test both Guro area and Woomyeon area for efficient experiment. In fact, we can test anywhere in the WiBro service area i.e., Seoul metropolitan area. The figure 7 shows a result of the field trial both local server and MS in the vehicle. The three cars as shown A, B and C in figure 7 (a) run in the same direction. The local server maintains vehicle identification, longitude, latitude and directional angle for all vehicles and displays all vehicles on the map. When we generate accident signal in the car C, the car C sends ACDT-REG-REQ message to the local server. The local server displays influence area such as emergency, warning and careful area based on algorithm as shown in figure 7 (a). The local server broadcasts ACDT-WRN message to the MS in vehicles based on proposed algorithm which calculates directional angle and distance between accident vehicle and neighbour vehicles. The car A and B response ACDT-RSP messages to the local server and the driver recognize the accident in front of the 685m as shown figure 7 (b). The MS displays remaining time is 75 seconds to the accident point. The remaining time and distance from MS to the accident point change depending vehicle speed.



(a) An example of local server accident registration (b) An example of MS for accident warning

(Figure 7) Example of accident both local server and MS in the vehicle

We measure delay time with proposed algorithm to evaluate performance with equation (6) in the real world as shown in figure 8. The results of the test at two different areas are similar. The delay time for between the vehicles is distributed from 60msec to 550msec. These results are satisfied with the requirements of latency for approaching emergency vehicle warning and almost all of the non-safety application [4].



(Figure 8) Time synchronization with GPS signal and message flow

5 CONCLUSION

We propose to use WiBro, one of the profiles for mobile WiMAX, for VANET infrastructure. We describe WiBro network architecture and requirement to use WiBro network. We propose algorithm for emergency vehicle warning which is one of the important applications. The algorithms are for node selection to receive warning messages from accident vehicle via local server. It includes directional angle of driving vehicle, distance calculation between the vehicles, classification of influence area and delay measurement algorithms.

We implement and verify the proposed algorithms in the real world. The results of the test are satisfied with the requirements of latency for approaching emergency vehicle warning and almost all of the non-safety application. Also, we can estimate WiBro is better than DSRC for VANET infrastructure. First, the WiBro can provide more application than DSRC described in [4]. Second, Though DSRC has been performed R&D in ITS for decades, a limited applications are possible now. The WiBro can provide Internet service and ITS application with little efforts. Third, the WiBro can support multimedia application for large scale, however the DSRC can possible limited applications due to its radio coverages.

The further research issues to use WiBro for VANET are development of integrated mobile station for Internet application and vehicular application described in [3],[4],[24]. We will improve the performance for the local server and develop accurate algorithms for directional angle.

Acknowledgement

This research was partly supported by a grant (07 Technology Innovation A01) from Construction Technology Innovation Program Smart Highway Project funded by Ministry of Land, transport and Maritime Affairs of Korean government.

References

[1] Marco Conti and Silvia Giordano, “Multihop Ad Hoc Networking: The Reality”, IEEE Comm. Magazine, April 2007, pp88-95

[2] Hannes Hartenstein and Kenneth P. Laberteaux, “A Tutorial Survey on Vehicular Ad Hoc Networks”, IEEE Comm. Magazine, June 2008, pp164-171

[3] Elmar Schoch, Frank Kargl and Michael Weber, “Communication patterns in VANETs”, IEEE Comm. Magazine, November 2008, pp119-125

[4] Vehicle Safety Communication Project, "Task 3 Final Report: Identify Intelligent Vehicle Safety Applications Enabled by DSRC", U.S. Dept. of Transportation, March 2005

[5] S. Corson and J. Macker, "Mobile Ad hoc Networking (MANET):Routing Protocol Performance Issues and Evaluation Considerations", IETF RFC 2051, January 1999

[6] Jeremy. J. Blum, Azim. Eskandarian, and Lance J. Hoffman, "Challenges of Intervehicle Ad Hoc Networks", IEEE Trans. Intell. Transport. Sys., Vol5, No4, December 2004, pp347-351

[7] Syed Ahson and Mohammad Ilyas, "WiMAX Standard and Security", CRC Press, pp147-173

[8] Sunil Kumar, Vineet S. Raghavan and Jing Deng, "Medium Access Control protocols for ad hoc wireless networks: A survey", Ad Hoc Networks, Vol. 4, Issues 3, May 2006, pp326-358

[9] Rajmohan Rajaraman, "Topology control and routing in ad hoc networks: a survey", ACM SIGACT News, Vol. 33, Issues 2, 2002, pp60-73

[10] Paolo Santi, "Topology Control in Wireless Ad Hoc and Sensor Network", John Wiley & Sons, 2005

[11] Jeffrey Andrews et al, "Multihop Ad Hoc Networking: The Theory", IEEE Comm. Magazine, April 2007, pp78-86

[12] Xiaoyan Hong, Kaixin Xu and Mario Gerla, "Scalable Routing Protocols for Mobile Ad Hoc Networks", IEEE Network, July/August 2002, pp11-21

[13] Kilian Weniger and Martina Zitterbart, "Address Autoconfiguration in Mobile Ad Hoc Networks: Current Approaches and Future Directions", IEEE Network July/August 2004, pp6-11

[14] Christopher N. Ververidis and George C. Polyzos, "Service Discovery for Mobile Ad Hoc Networks: A Survey of Issues and Techiques", IEEE Comm. Surveys & Tutorials, Vol. 10, Issues 3, 2008, pp30 - 45

[15] Lajos Hanzo II and Rahim Tafazolli, "A Survey of QoS Routing Solutions for Mobile Ad Hoc Networks", IEEE Comm. Surveys & Tutorials, Vol. 9, Issues 1, 2007, pp14 - 30

[16] Ian F. Akyildiz, Xudong Wang and Weilin Wang, "Wireless mesh networks: a survey", Computer Networks, Vol. 47, Issues 4, March 2005, pp445-487

[17] IEEE Std 802.16-2004, "Local and Metropolitan Area Networks – Part 16: Air Interface for Fixed Broadband Wireless Access System", October 2004

[18] IEEE Std 802.16e-2005, "Local and Metropolitan Area Networks – Part 16: Air Interface for Fixed Broadband Wireless Access System – Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands", February 2006

[19] V. Devarapalli, R. Wakikawa, A. Petrescu, P. Thubert, "Network Mobility (NEMO) Basic Support Protocol", IETF RFC 3963, January 2005

[20] C. Perkins, "IP Mobility Support for IPv4", IETF RFC 3344, August 2002

[21] D. Johnson, C. Perkins, J. Arkko, "Mobility Support in IPv6", IETF RFC 3775, June 2004

[22] S. Gundavelli, K.Leung, V. Devarapalli, K. Chowdhury and B. Patil, "Proxy Mobile IPv6", IETF RFC 5213, August 2008

[23] Andreas Festag, Holger F¨ußler, Hannes Hartenstein, Amardeo Sarma, and Ralf Schmitz, "FLEETNET: Bringing Car-to-Car Communication into the real world", Proceedings of the 11th World Congress on ITS, Nagoya, Japan, October 2004

[24] Richard Bossom et al, "D31 European ITS Communication Architecture Overall Framework Proof of Concept Implementation" Communication for eSafety (COMeSafety) project, March 2009

[25] Arnor Solberg et al, "Architecture and System Specifications", Cooperative Vehicle-Infrastructure Systems (CVIS) Projects, July 2007

[26] WiMAX Forum, "Network Architecture Stage 2: Architecture Tenets, Reference Model and Reference Points, Part1 – Release 1.0 Version 4", February 2009

[27] Kamran Etemad, "Overview of Mobile WiMAX Technology and Evolution", IEEE Comm. Magazine, October 2008, pp31-40

[28] C. Rigney, S. Willens, A. Rubens, W. Simpson, "Remote Authentication Dial In User Service (RADIUS)", IETF RFC 2865, June 2000

[29] P. Calhoun, J. Loughney, E. Guttman, G. Zorn, J. Arkko, "Diameter Base Protocol", IETF RFC 3588, September 2003

[30] R. Droms, "Dynamic Host Configuration Protocol", IETF RFC 2131, March 1997

[31] http://www.movable-type.co.uk/scripts/latlong.html

[32] J. Postel, User Datagram Protocol, IETF RFC 768, August 1980